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# Three dimensional (3d) transverse oscillation vector velocity ultrasound imaging.

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*Publication date:*
2013

*Document Version*
Publisher's PDF, also known as Version of record

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
18 April 2013 (18.04.2013)

WIPO | PCT

(10) International Publication Number
WO 2013/054149 A1

(51) International Patent Classification:
*G01P 5/24* (2006.01) *G01S 15/89* (2006.01)
*G01S 15/58* (2006.01) *A61B 8/06* (2006.01)

(21) International Application Number: PCT/IB2011/002383

(22) International Filing Date: 11 October 2011 (11.10.2011)

(25) Filing Language: English

(26) Publication Language: English

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

**Declarations under Rule 4.17**:
— *as to the identity of the inventor (Rule 4.17(i))*
— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*
— *of inventorship (Rule 4.17(iv))*

**Published**:
— *with international search report (Art. 21(3))*

**(54) Title**: THREE DIMENSIONAL (3D) TRANSVERSE OSCILLATION VECTOR VELOCITY ULTRASOUND IMAGING

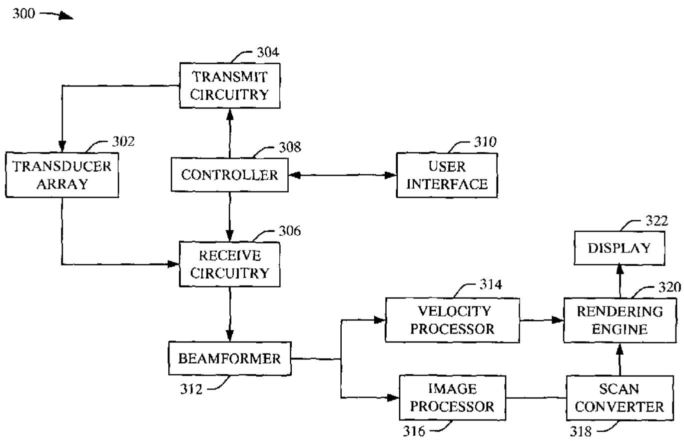


FIGURE 3

**(57) Abstract**: An ultrasound imaging system (300) includes a transducer array (302) with a two- dimensional array of transducer elements configured to transmit an ultrasound signal and receive echoes, transmit circuitry (304) configured to control the transducer array to transmit the ultrasound signal so as to traverse a field of view, and receive circuitry (306) configured to receive a two dimensional set of echoes produced in response to the ultrasound signal traversing structure in the field of view, wherein the structure includes flowing structures such as flowing blood cells, organ cells etc. A beamformer (312) configured to beamform the echoes, and a velocity processor (314) configured to separately determine a depth velocity component, a transverse velocity component and an elevation velocity component, wherein the velocity components are determined based on the same transmitted ultrasound signal and the same received set of two dimensional echoes form part of the imaging system.

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# THREE DIMENSIONAL (3D) TRANSVERSE OSCILLATION VECTOR VELOCITY ULTRASOUND IMAGING

## TECHNICAL FIELD

The following generally relates to ultrasound imaging and more particularly to three dimensional (3D) transverse oscillation vector velocity ultrasound imaging which can be used to estimate the spatial velocity components (depth, transverse and elevation) of blood flow velocity and/or moving tissue structures.

## BACKGROUND

Ultrasound imaging provides useful information about the interior characteristics of an object or subject such as a human or animal patient. In one instance, an ultrasound scanner has been used to estimate blood flow velocity and generate one or more images of the interior characteristics with the estimated blood velocity superimposed there over.

With conventional ultrasound imaging blood flow velocity estimation, a pulse-echo field only oscillates in the axial direction along the axis of the ultrasound beam. This is illustrated in Figure 1 in which an ultrasound beam 102 propagates along a $z$-axis 104 and only the axial velocity component (vz) 106 along the $z$-axis or depth can be estimated; the transverse velocity components vx 108 and vy 110 cannot be estimated. Blood scatterers passing through the field of interest will produce a signal with a frequency component proportional to the axial velocity. The basic mechanism that allows the traditional estimation of axial velocities is the oscillations in the transmitted pulse.

The transverse oscillation (TO) blood velocity estimation approach has been used to estimate vz and vx. Using the same basic mechanism noted above, a transverse oscillation is introduced in the ultrasound field, and this oscillation generates received signals that depend on the transverse oscillation. The basic idea is to create a double-oscillating pulse-echo field using a one dimensional (1D) transducer array. This had been accomplished by using the same transmit beam as used in conventional velocity estimation and particularly predetermined apodization profiles in receive. Suitable apodization functions are discussed in J. A. Jensen and P. Munk, "A New Method for Estimation of Velocity Vectors," IEEE Trans. Ultrason., Ferroelec., Freq. Contr., vol. 45, pp. 837–851, 1998, and J. Udesen and J. A. Jensen, "Investigation of Transverse Oscillation Method," IEEE Trans. Ultrason., Ferroelec., Freq. Contr., vol. 53, pp. 959–971, 2006.

Figure 2 shows an example of the TO approach for estimating vz and vx. In this example, the transverse oscillations are created in receive, and two lines are beamformed in parallel to get the spatial lateral in-phase (I) and quadrature (Q) components. The spatial IQ samples, $r_{IQ}$, are obtained by $r_{IQ}(t) = r_I(t) + jr_Q(t)$, where $r_I$ and $r_Q$ are the samples at time t from the left and right beam, respectively. Along with the two TO lines, a center line can be beamformed for conventional axial or depth velocity estimation. Using the Fraunhofer approximation, the relation between the lateral spatial wavelength and the apodization function is: $\lambda_x = 2\lambda_z z_0 / d$, where d is the distance between the two peaks in the apodization function, $z_0$ is depth, and $\lambda_z$ is the axial wavelength.

From the above apodization function, the lateral wavelength ($\lambda_x$) increases as the depth ($z_0$) increases, if the apodization function (d) is kept constant. To keep a constant lateral wavelength ($\lambda_x$), the aperture must expand with depth ($z_0$). Using a phased array, the width is often limited, so instead the spacing between the two beamformed lines can be increased through depth. Keeping the apodization function fixed, the two lines can be beamformed with a fixed angle. Using the tangent-relation, the angle, $\theta$, between the two lines can be derived as $\theta/2 = \arctan((\lambda_x / 8) / z_0) = \arctan(\lambda_z / 4d)$.

If $r_{IQ}$ is the spatial IQ signal, then the corresponding temporal IQ signal can be referred to as $r_{IQ,h}$, and two new signals, $r_1$ and $r_2$, can be generated $r_1(k) = r_{IQ}(k) + jr_{IQ,h}(k)$ and $r_2(k) = r_{IQ}(k) - jr_{IQ,h}(k)$, where k denotes discrete samples. The transverse velocity (vx) can then be calculated by:

$$\mathrm{vx} = \left(\frac{\lambda_x}{2\pi 2kT_{prf}}\right)\arctan\left(\frac{\Im\{R_1(k)\}\Re\{R_2(k)\} + \Im\{R_2(k)\}\Re\{R_1(k)\}}{\Re\{R_1(k)\}\Re\{R_2(k)\} - \Im\{R_2(k)\}\Im\{R_1(k)\}}\right),$$

where $T_{prf}$ is the time between two pulses, $R_1(k)$ is the complex lag k autocorrelation value for $r_1(k)$, and $R_2(k)$ is the complex lag k autocorrelation value for $r_2(k)$. The complex autocorrelation is estimated over N shots, and is typically spatially averaged over a pulse length.

Three dimensional (3D) velocity approaches for estimating vz, vx and vy are discussed in M. D. Fox, "Multiple crossed-beam ultrasound Doppler velocimetry," IEEE Trans. Son. Ultrason., vol. SU-25, pp. 281–286, 1978, and G. E. Trahey, J. W. Allison, and O. T. von Ramm, "Angle independent ultrasonic detection of blood flow," IEEE

Trans. Biomed. Eng., vol. BME-34, pp. 965–967, 1987. Unfortunately, Fox uses a multi-beam approach that requires trigonometry to determine velocity, and Trahey uses speckle tracking (normalized cross-correlation) to determine a three dimensional (3D) velocity vector from the entire acquired 3D volume of data.

## SUMMARY


Aspects of the application address the above matters, and others.

In one aspect, an ultrasound imaging system includes a transducer array with a two-dimensional array of transducer elements configured to transmit an ultrasound signal and receive echoes, transmit circuitry configured to control the transducer array to transmit the ultrasound signal so as to traverse a field of view, and receive circuitry configured to receive a two dimensional set of echoes produced in response to the ultrasound signal traversing structure in the field of view, wherein the structure includes flowing structure. A beamformer configured to beamform the echoes, and a velocity processor configured to separately determine a depth velocity component, a transverse velocity component and an elevation velocity component, wherein the velocity components are determined based on the same transmitted ultrasound signal and the same received set of two dimensional echoes.

In another aspect, a method includes receiving a two dimensional set of echoes corresponding to a same transmit ultrasound signal. The method further includes concurrently generating a line of data along a z direction in which the transmitted ultrasound signal traverses, a pair of lines of data in a z-x plane, and a pair of lines of data in a z-y plane, which is perpendicular to the z-x plane based on the received two dimensional set of echoes. The method further includes estimating a depth velocity component based on the line of data, a transverse velocity component based on the pair of lines of data in a z-x plane, and an elevation velocity component pair of lines of data in a z-y plane.

In another aspect, a velocity processor includes a depth velocity processor, a transverse velocity processor, and an elevation velocity processor. The depth, transverse velocity and elevation velocity processors respectively generates signals indicative of a depth velocity component in a z direction along which a transmit ultrasound signal traverses, a transverse velocity component traversing a z-x plane, and an elevation velocity

component traversing a z-y plane, based on a two dimensional set of echoes received in response to the same transmit ultrasound signal.

Those skilled in the art will recognize still other aspects of the present application upon reading and understanding the attached description.

## BRIEF DESCRIPTION OF THE DRAWINGS

The application is illustrated by way of example and not limited by the figures of the accompanying drawings, in which like references indicate similar elements and in which:

Figure 1 illustrates a prior art approach to estimating flow and/or tissue velocity along the depth of the transmitted ultrasound signal;

Figure 2 illustrates a prior art approach to estimating flow and/or tissue velocity along the depth of the transmitted ultrasound signal and along a transverse direction;

Figure 3 schematically illustrates an example ultrasound imaging system in connection with a beamformer and velocity processor for determining velocity in depth, transverse and elevation directions;

Figure 4 schematically illustrates examples of the beamformer and velocity processor of Figure 3;

Figure 5 illustrates beamformed lines for producing data for determining velocity in depth, transverse and elevation directions,

Figure 6 illustrates a method; and

Figure 7 schematically illustrates a variation of the embodiment of Figure 4.

## DETAILED DESCRIPTION

Initially referring to Figure 3, an example ultrasound imaging system 300 is illustrated.

A transducer array 302 includes a two dimensional (2D) array of transducer elements, which are configured to transmit ultrasound signals and receive echo signals. Examples of suitable 2D arrays include 32x32, 64x64, and/or other dimension arrays, including square and/or rectangular arrays. The array can be linear, curved, and/or otherwise shaped. The array can be fully populated or sparse and/or a combination hereof.

Transmit circuitry 304 generates a set of pulses that are conveyed to the transducer array 302. The set of pulses actuates a corresponding set of the transducer elements of the transducer array 304, causing the elements to transmit ultrasound signals into an examination or scan field of view. In the illustrated embodiment, transmit circuitry 304 generates a set of pulses which produce a transmit signal suitable at least for velocity imaging.

Receive circuitry 306 receives echoes generated in response to the transmitted ultrasound signals from the transducer 302. The echoes, generally, are a result of the interaction between the emitted ultrasound signals and the structure (e.g., flowing blood cells, organ cells, etc.) in the scan field of view.

A controller 308 controls one or more of the transmit circuitry 304 or receive circuitry 306. Such control can be based on available modes of operation (e.g., velocity flow, A-mode, B-mode, etc.) of the system 300. In addition, such control can be based on one or more signals indicative of input from a user via a user interface (UI) 310. The UI 310 may include one or more input devices (e.g., a button, a knob, a slider, a touch pad, etc.) and/or one or more output devices (e.g., a display screen, lights, a speaker, etc.).

A beamformer 312 processes the echoes, for example, by applying time delays, weighting on the channels, summing, and/or otherwise beamforming received echoes. As described in greater detail below, in one instance, the beamformer 312 includes a plurality of beamformers that simultaneously process the echoes and produce data for determining the three dimensional (3D) velocity components, vz (depth velocity), vx (transverse velocity) and vy (elevation velocity). The illustrated beamformer 312 also produces data for generating images in A-mode, B-mode, and/or other modes.

A velocity processor 314 processes the beamformed data output by the beamformer 312 output. This includes processing the beamformed data to determine one or more of the 3D velocity components, vz, vx or vy. As described in greater detail below, in one instance the velocity processor 314 individually and separately estimates vz, vx or vy based on a same transmission ultrasound signal and the corresponding two dimensional (2D) acquired data.

An image processor 316 also receives the beamformed data from the beamformer 312. For B-mode, the image processor 316 processes the data and generates a sequence of focused, coherent echo samples along focused scanlines of a scanplane. The image processor 316 may also be configured to process the scanlines to lower speckle and/or improve specular reflector delineation via spatial compounding and/or perform other processing such as FIR filtering, IIR filtering, etc.

A scan converter 318 scan converts the output of the image processor 316 to generate data for display, for example, by converting the data to the coordinate system of the display. The scan converter 318 can be configured to employ analog and/or digital scan converting techniques.

A rendering engine 320 visually presents one or more images and/or velocity information via a display monitor 322. Such presentation can be in an interactive graphical user interface (GUI), which allows the user to selectively rotate, scale, and/or manipulate the displayed data. Such interaction can be through a mouse or the like, and/or a keyboard or the like, touch-screen controls and/or the like, and/or other known and/or approach for interacting with the GUI.

It is to be appreciated that the beamformer 312 and/or the velocity processor 314 can be implemented via a processor executing one or more computer readable instructions encoded or embedded on computer readable storage medium such as physical memory. Such a processor can be part of the system 300 and/or a computing device remote from the system 300. Additionally or alternatively, the processor can execute at least one computer readable instructions carried by a carrier wave, a signal, or other non-computer readable storage medium such as a transitory medium.

Figures 4 and 5 illustrate a non-limiting example. Figure 4 depicts examples of the beamformer 312 and the velocity processor 314, and Figure 5 depicts the beamformed data used to determine the velocities vz, vx and/or vy. For this example, the transmit circuitry 304 (Figure 3) controls the transducer array 302 (Figure 3) so that a lateral width of the transmitted pulse is broad enough to cover the beamformed receive lines. This can be done using a high F-number, a focal depth further away than the depth of interest, plane waves, or other approach. The transverse oscillations are created in receive.

The beamformer 312 includes five (5) beamformers 402, 404, 406, 408 and 410. The beamformer 402 is configured to produce data for determining vz, the beamformers 404 and 406 are configured to produce data for determining vx, and beamformers 408 and 410 are configured to produce data for determining vy. The beamformers 404 and 406 have apodization peaks that are separated or spaced apart by a predetermined distance and simultaneously create the lines Ix and Qx in the z-x plane. The beamformers 408 and 410 have apodization peaks that are separated or spaced apart by a predetermined distance and simultaneously create the lines Iy and Qy in the z-y plane. The apodization of vx and vy is ninety degrees ($90^{\circ}$) apart.

In this example, the lines Ix, Qx, Iy and Qy are beamformed based on a same fixed angle $\theta$ that corresponds to an increasing lateral wavelength. In another embodiment, the lines Ix and Qx and the lines Iy and Qy can be beamformed based on different fixed angles or a fixed distance between them. In this example, all five of the lines z, Ix, Qx, Iy and Qy are beamformed simultaneously. In another embodiment, all five of the lines z, Ix, Qx, Iy and Qy are not beamformed simultaneously. In yet another embodiment, the beamformer 312 includes more than five beamformers in which several velocity image lines are beamformed in parallel.

The velocity processor 314 includes a depth processor 412 that processes the data generated by the beamfomer 402 and estimates vz, a transverse processor 414 that processes the data generated by the beamfomers 404 and 406 and estimates vx, and an elevation processor 416 that processes the data generated by the beamfomers 408 and 410 and estimates vy. The depth processor 412 can use a conventional autocorrelation and/or other approach to estimate vz. The transverse processor 414 and the elevation processor 416 can use a transverse oscillation (TO) approach to determine vx and vy.

For example, from above, for vx, the Fraunhofer approximation can be used to determine the $\lambda_x = 2\lambda_z z_0 / d$, where d is the distance between the two peaks in the apodization function, $z_0$ is depth, and $\lambda_z$ is the axial wavelength. Alternatively, $\lambda_x$ can be determined based on the simulated or measured pulse-echo field. The Fraunhofer approximation can similarly be used for vy in which the relation is $\lambda_y = 2\lambda_z z_0 / d$. Using the tangent-relation, the angle between the two lines is $\theta/2 = \arctan((\lambda_y / 8) / z_0) = \arctan(\lambda_y / 4d)$. Using the same constraints as used for vx, the elevation velocity (vy) can then be calculated by:

$$\mathrm{vy} = \left(\frac{\lambda_y}{2\pi 2kT_{prf}}\right)\arctan\left(\frac{\Im\{R_1(k)\}\Re\{R_2(k)\} + \Im\{R_2(k)\}\Re\{R_1(k)\}}{\Re\{R_1(k)\}\Re\{R_2(k)\} - \Im\{R_2(k)\}\Im\{R_1(k)\}}\right),$$

where $T_{prf}$ is the time between two pulses, $R_1(k)$ is the complex lag k autocorrelation value for $r_1(k)$, and $R_2(k)$ is the complex lag k value for $r_2(k)$. From above,

$$\mathrm{vx} = \left(\frac{\lambda_x}{2\pi 2kT_{prf}}\right)\arctan\left(\frac{\Im\{R_1(k)\}\Re\{R_2(k)\}+\Im\{R_2(k)\}\Re\{R_1(k)\}}{\Re\{R_1(k)\}\Re\{R_2(k)\}-\Im\{R_2(k)\}\Im\{R_1(k)\}}\right).$$

Figure 6 illustrates an example method for employing the ultrasound imaging system.

It is to be understood that the following acts are provided for explanatory purposes and are not limiting. As such, one or more of the acts may be omitted, one or more acts may be added, one or more acts may occur in a different order (including simultaneously with another act), etc.

At 600, an ultrasound signal is transmitted into a field of view.

At 602, echoes, in response to the ultrasound signal, are received by a two dimensional transducer array.

At 604, the echoes are beamformed to produce a line along the depth direction z.

At 606, the echoes are beamformed to produce two lines, separated by a fixed angle, in the z-x plane.

At 608, the echoes are beamformed to produce two lines, separated by a fixed angle, in the z-y plane.

In this embodiment, acts 604-608 are performed concurrently and independently. However, it is to be appreciated that acts 604-608 do not have to be performed concurrently and independently.

At 610, vz is determined based on the line in the depth direction z, for example, using autocorrelation.

At 612, vx is determined based on the two lines in the z-x plane using the transverse oscillation approach.

At 614, vz is determined based on the two lines in the z-y plane using the transverse oscillation approach.

At 616, the velocities vz, vx and vy are visually presented. In one instance, this includes superimposing the data corresponding to the velocities vz, vx and vy over a B-mode or other image.

The methods described herein may be implemented via one or more processors executing one or more computer readable instructions encoded or embodied on computer readable storage medium such as physical memory which causes the one or more processors to carry out the various acts and/or other functions and/or acts.

Additionally or alternatively, the one or more processors can execute instructions carried by transitory medium such as a signal or carrier wave.

Figure 7 schematically illustrates a variation of the embodiment of Figure 4. In this variation, only four (4) lines are beamformed instead of five (5). More specifically, the beamfomers 404 and 406 beamform respective lines, which the transverse velocity processor 414 processes, using a TO approach, to estimate vx, and the beamfomers 408 and 410 beamform respective lines, which the elevation velocity processor 416 processes, using a TO approach, to estimate vy. In this variation, the velocity processor 314 includes a depth velocity estimator 702, which estimates vz based on the two lines used to determine vx and/or the two lines used to determine vy. The beamformer 402 and/or the depth velocity processor 412 can be omitted. In another variation, the depth velocity processor 412 and the depth velocity estimator 702 are part of the same depth velocity component.

The application has been described with reference to various embodiments. Modifications and alterations will occur to others upon reading the application. It is intended that the invention be construed as including all such modifications and alterations, including insofar as they come within the scope of the appended claims and the equivalents thereof.

## CLAIMS

What is claimed is:

1. An ultrasound imaging system (300), comprising:

a transducer array (302), including a two-dimensional array of transducer elements configured to transmit an ultrasound signal and receive echoes;

transmit circuitry (304) configured to control the transducer array to transmit the ultrasound signal so as to traverse a field of view;

receive circuitry (306) configured to receive a two dimensional set of echoes produced in response to the ultrasound signal traversing structure in the field of view, wherein the structure includes flowing structure;

a beamformer (312) configured to beamform the echoes; and

a velocity processor (314) configured to separately determine a depth velocity component, a transverse velocity component and an elevation velocity component, wherein the velocity components are determined based on the same transmitted ultrasound signal and the same received set of two dimensional echoes.

2. The system of claim 1, wherein the beamformer concurrently beamforms the echoes and generates data processed by the velocity processor to determine the depth velocity component, the transverse velocity component and the elevation velocity component.

3. The system of claim 2, wherein the beamformer beamforms a pair of lines of data in a depth/transverse plane, and the velocity processor, including:

a transverse velocity processor (414) that determines the transverse velocity component based on the pair of lines of data in the depth/transverse plane.

4. The system of claim 3, wherein the transverse velocity processor determines the transverse velocity component based on a first transverse oscillation.

5. The system of any of claims 2 to 3, wherein the beamformer beamforms a pair of lines of data in a depth/elevation plane, and the velocity processor, further including:

an elevation velocity processor (416) that determines the elevation velocity component based on the pair of lines of data in the depth/elevation plane.

6. The system of claim 5, wherein the elevation velocity processor determines the elevation velocity component based on a second transverse oscillation.

7. The system of any of claims 3 to 6, wherein pairs of two lines beamformed by the beamformer include lines that are separated by a fixed receive angle.

8. The system of any of claims 3 to 7, wherein sets of two lines beamformed by the beamformer are separated by a quarter wavelength.

9. The system of any of claims 7 to 8, wherein the angle corresponds to an increasing lateral wavelength.

10. The system of any of claims 5 to 9, the velocity processor, further including:

a depth velocity estimator (702) that estimates the depth velocity component based on at least one of the pair of lines of data in the depth/transverse plane or the pair of lines of data in the depth/elevation plane.

11. The system of any of claims 2 to 9, wherein the beamformer beamforms a line of data along a depth direction of the transmitted ultrasound signal, and the velocity processor, further including:

a depth velocity processor (412) that determines the depth velocity component based on the line.

12. The system of claim 10, wherein the depth velocity processor determines the depth velocity component based on autocorrelation.

13. The system of any of claims 1 to 12, wherein the depth velocity component, the transverse velocity component and the elevation velocity component are perpendicular to each other.

14. The system of any of claims 1 to 13, wherein the depth velocity component represents velocity along a direction of the transmitted ultrasounds signal, the transverse velocity component represents velocity along a direction perpendicular to the direction of the depth velocity component, and the elevation velocity component represents velocity along a direction perpendicular to both the direction of the depth velocity component and the direction of the transverse velocity component.

15 The system of any of claims 1 to 14, wherein the beamformer beamforms five or less scanlines to produce the data used to determine the depth velocity component, the transverse velocity component and the elevation velocity component.

16. A method, comprising:

receiving a two dimensional set of echoes corresponding to a same transmit ultrasound signal;

concurrently generating a line of data along a z direction in which the transmitted ultrasound signal traverses, a pair of lines of data in a z-x plane, and a pair of lines of data in a z-y plane, which is perpendicular to the z-x plane, based on the received two dimensional set of echoes; and

estimating a depth velocity component based on the line of data, a transverse velocity component based on the pair of lines of data in a z-x plane, and an elevation velocity component pair of lines of data in a z-y plane.

17. The method of claim 16, further comprising:

estimating the three velocity components individually and separately from each other.

18. The method of any of claims 16 to 17, further comprising:

estimating the depth velocity component based on autocorrelation.

19. The method of any of claims 16 to 18, further comprising:

estimating the transverse velocity component based on a first transverse oscillation.

20. The method of any of claims 16 to 19, further comprising:
estimating the elevation velocity component based on a second transverse oscillation.

21. The method of any of claims 19 to 20, further comprising:
estimating the depth velocity component based on scanlines used to estimate at least one of the transverse velocity component or the elevation velocity component.

22. The method of any of claims 16 to 21, wherein the depth velocity component, the transverse velocity component and the elevation velocity component are perpendicular to each other.

23. The method of any of claims 16 to 22, wherein the depth velocity component represents velocity along a direction of the transmitted ultrasounds signal, the transverse velocity component represents velocity along a direction perpendicular to the direction of the depth velocity component, and the elevation velocity component represents velocity along a direction perpendicular to both the direction of the depth velocity component and the direction of the transverse velocity component.

24 The method of any of claims 16 to 23, wherein no more than five lines are generated.

25 The method of any of claims 16 to 24, wherein the three velocity components are not estimated based on trigonometry.

26 The method of any of claims 16 to 25, wherein the three velocity components are not estimated based on three dimensional data.

27. A velocity processor (314), comprising:
a transverse velocity processor (414); and
an elevation velocity processor (416),

wherein the transverse and elevation velocity processors respectively generate signals indicative of a transverse velocity component traversing a z-x plane and an elevation velocity component traversing a z-y plane, based on a two dimensional set of echoes received in response to the same transmit ultrasound signal.

28. The velocity processor of any of claim 27, wherein the transverse velocity and the elevation velocity processors respectively generate the transverse velocity component and elevation velocity component based on a transverse oscillation algorithm,

29. The velocity processor of any of claims 27 to 28, wherein the transverse velocity and elevation velocity processors respectively generate the signals based on exactly four lines beamformed from the two dimensional set of echoes, including a first pair of lines in the z-x plane and separated by a first angle, and a second pair of lines in the z-y plane and separated by a second angle.

30. The velocity processor of any of claims 27 to 29, further comprising:

a depth velocity component (412 or 702), wherein the depth velocity component generates a signal indicative of a depth velocity component in a z direction along which a transmit ultrasound signal traverses.

31. The velocity processor of claim 30, wherein the depth velocity component generates the signal based on at least one of the first pair of lines in the z-x plane and the second pair of lines in the z-y plane.

32. The velocity processor of claim 30, wherein the depth velocity component generates the signal based on a single line along the z-direction.

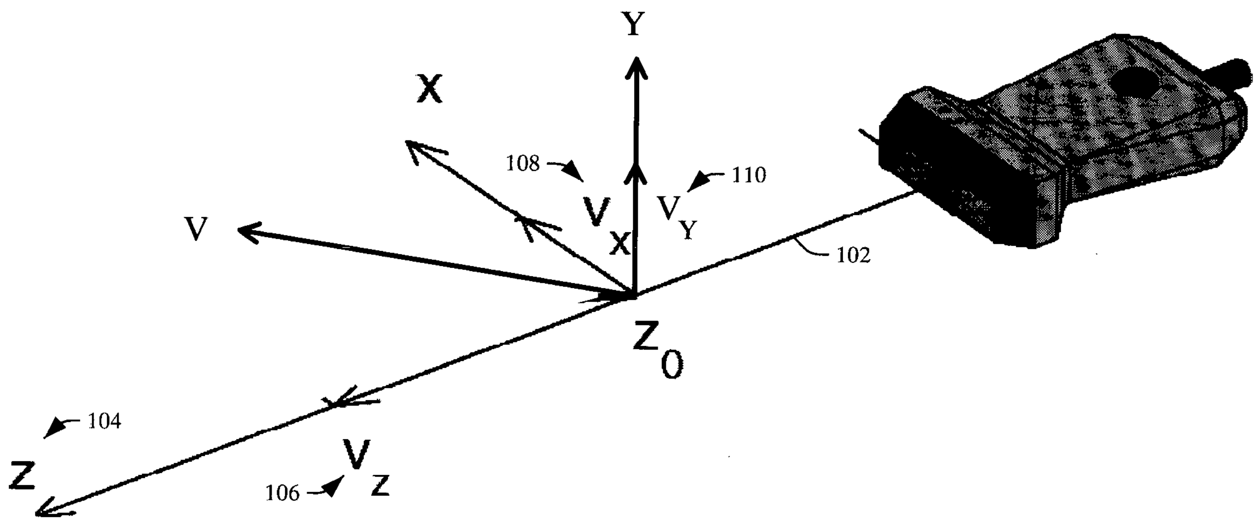


FIGURE 1
(PRIOR ART)

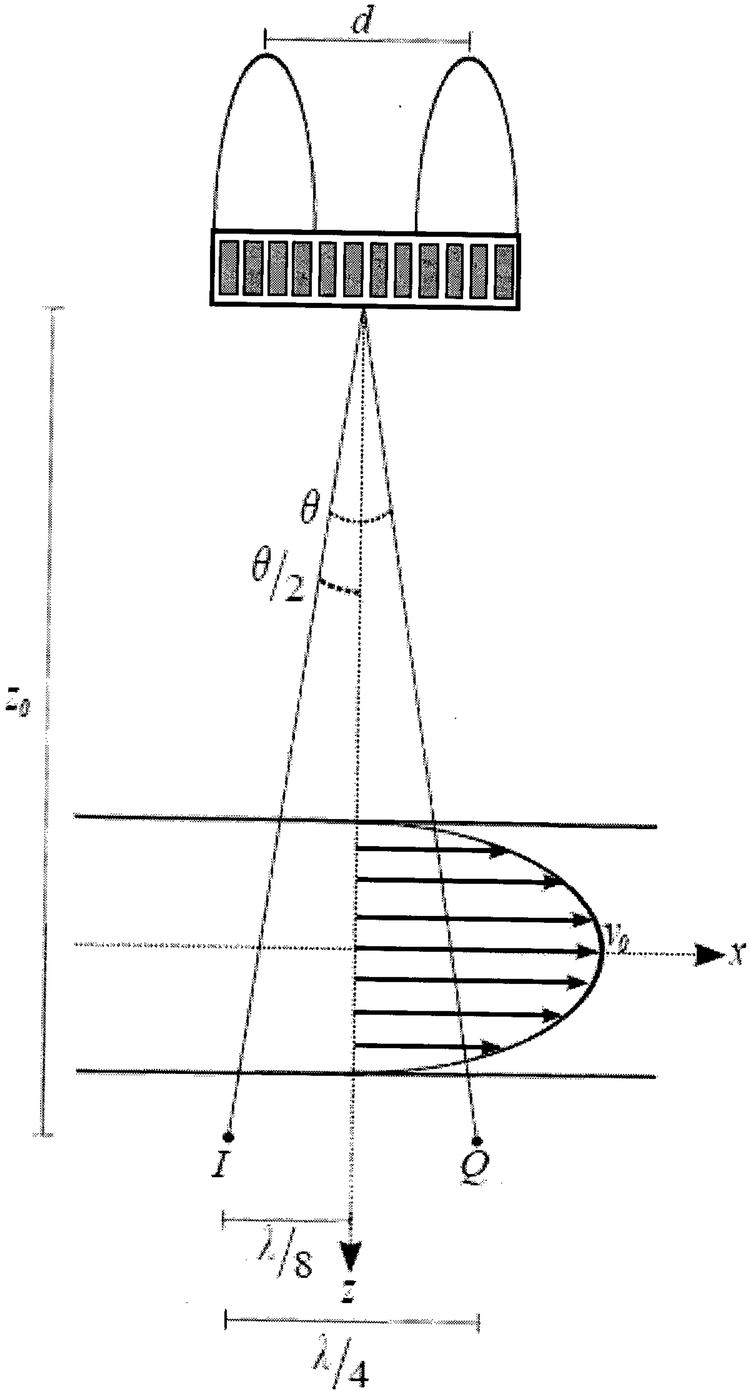


FIGURE 2
(PRIOR ART)

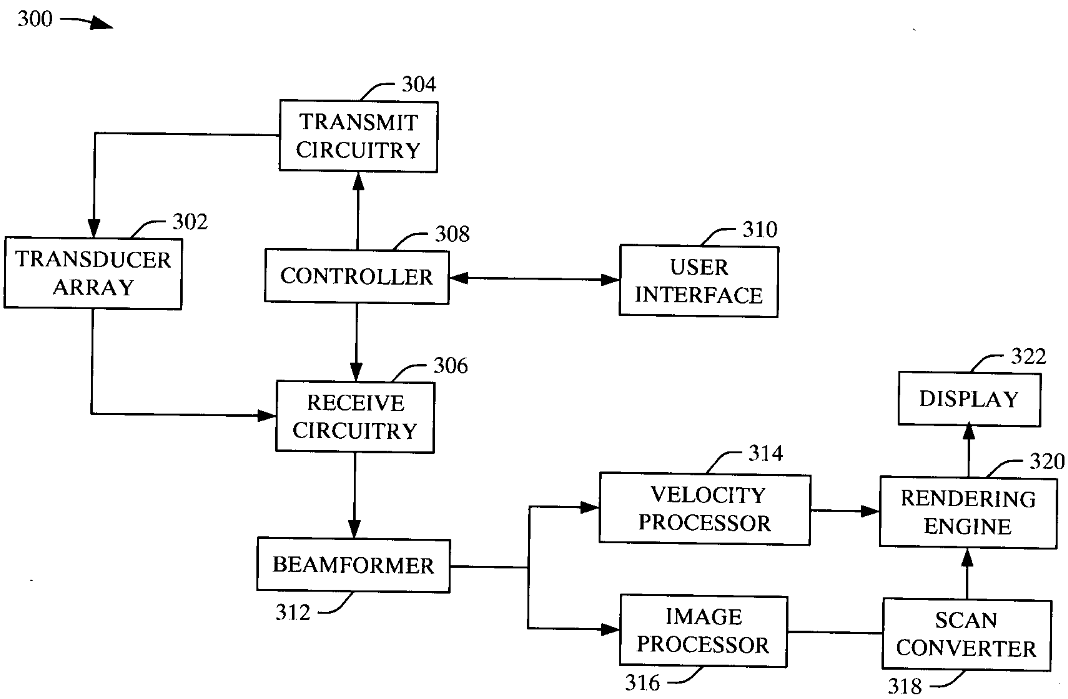
300
304
TRANSMIT CIRCUITRY
302
TRANSDUCER ARRAY
308
CONTROLLER
310
USER INTERFACE
306
RECEIVE CIRCUITRY
322
DISPLAY
314
VELOCITY PROCESSOR
320
RENDERING ENGINE
BEAMFORMER
312
IMAGE PROCESSOR
316
SCAN CONVERTER
318

FIGURE 3

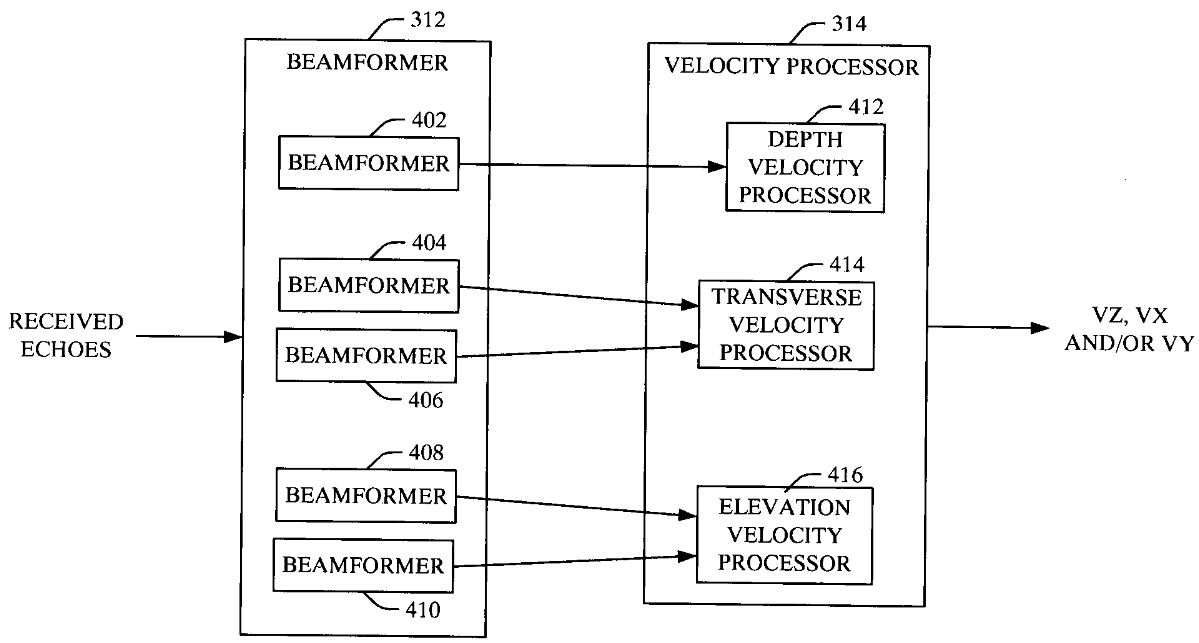
312
BEAMFORMER
402
BEAMFORMER
404
BEAMFORMER
BEAMFORMER
406
408
BEAMFORMER
BEAMFORMER
410
314
VELOCITY PROCESSOR
412
DEPTH VELOCITY PROCESSOR
414
TRANSVERSE VELOCITY PROCESSOR
416
ELEVATION VELOCITY PROCESSOR
RECEIVED ECHOES
VZ, VX AND/OR VY

FIGURE 4

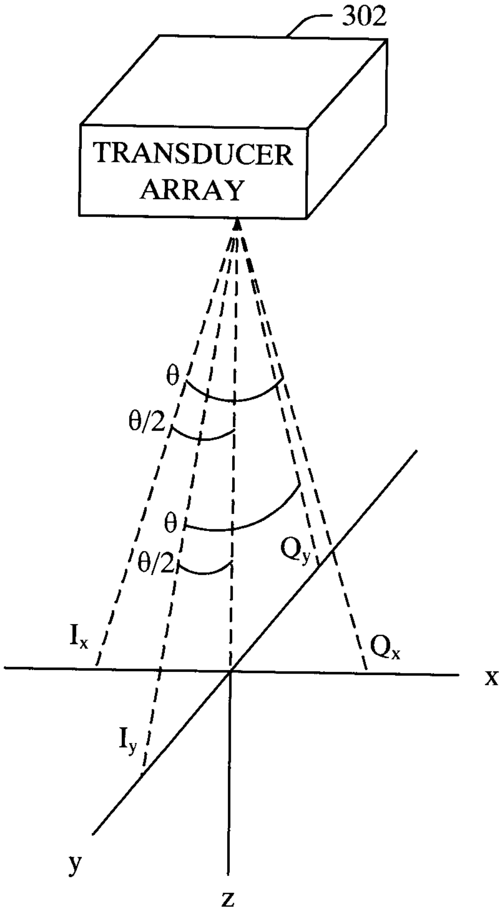


FIGURE 5

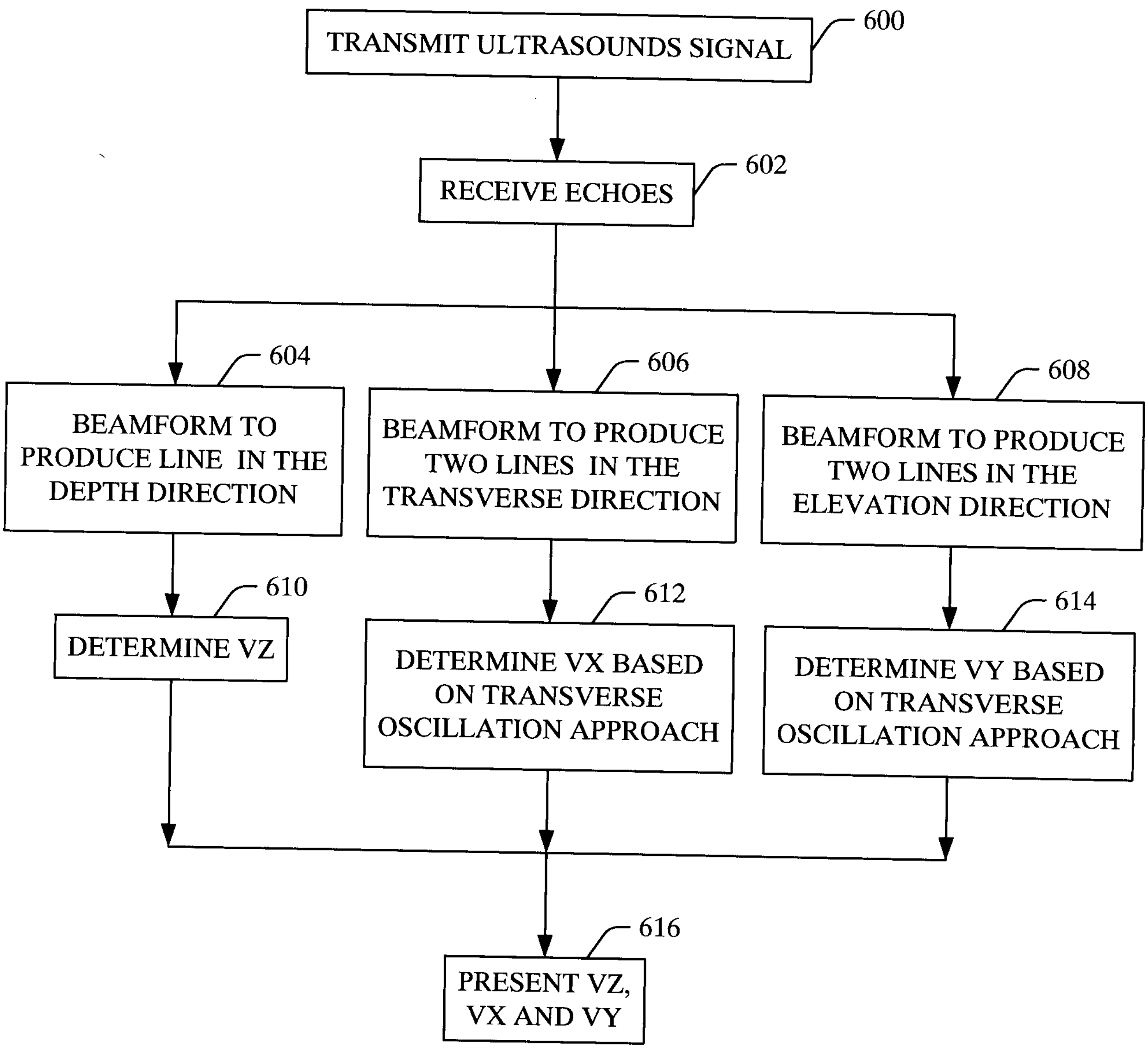
TRANSMIT ULTRASOUNDS SIGNAL
600
RECEIVE ECHOES
602
BEAMFORM TO PRODUCE LINE IN THE DEPTH DIRECTION
604
BEAMFORM TO PRODUCE TWO LINES IN THE TRANSVERSE DIRECTION
606
BEAMFORM TO PRODUCE TWO LINES IN THE ELEVATION DIRECTION
608
DETERMINE VZ
610
DETERMINE VX BASED ON TRANSVERSE OSCILLATION APPROACH
612
DETERMINE VY BASED ON TRANSVERSE OSCILLATION APPROACH
614
PRESENT VZ, VX AND VY
616

FIGURE 6

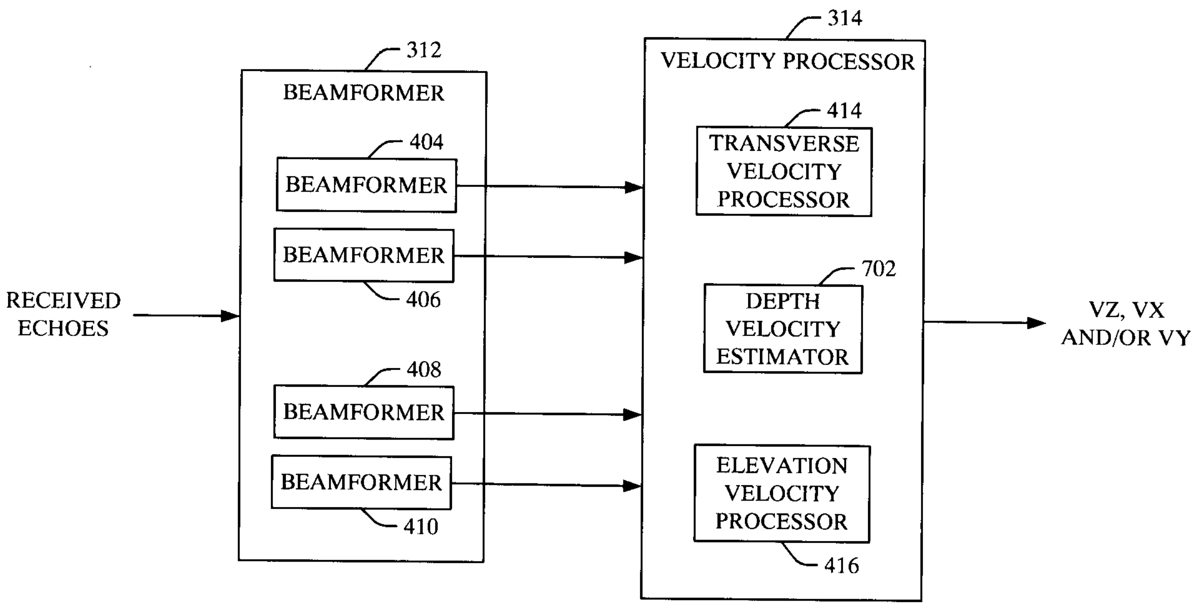
312
BEAMFORMER
404
BEAMFORMER
BEAMFORMER
406
408
BEAMFORMER
BEAMFORMER
410
RECEIVED ECHOES
314
VELOCITY PROCESSOR
414
TRANSVERSE VELOCITY PROCESSOR
702
DEPTH VELOCITY ESTIMATOR
ELEVATION VELOCITY PROCESSOR
416
VZ, VX AND/OR VY

FIGURE 7

# INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2011/002383

**A. CLASSIFICATION OF SUBJECT MATTER**
INV. G01P5/24 G01S15/58 G01S15/89 A61B8/06
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)
G01P G01S A61B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
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-/--

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 18 June 2012 | 03/07/2012 |

| Name and mailing address of the ISA/ | Authorized officer |
|---|---|
| European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016 | Mundakapadam, S |

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
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| A | JENSEN J A ET AL: "A new method for estimation of velocity vectors", IEEE TRANSACTIONS ON ULTRASONICS, FERROELECTRICS AND FREQUENCY CONTROL, IEEE, US, vol. 45, no. 3, 1 May 1998 (1998-05-01), pages 837-851, XP011437757, ISSN: 0885-3010, DOI: 10.1109/58.677749<br>the whole document | 1-32 |

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**Information on patent family members**

International application No
PCT/IB2011/002383

| Patent document cited in search report | | Publication date | Patent family member(s) | | | Publication date |
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